System Dynamics Model on Harmonious Development of Chinese Science & Technology, Education and Economy under High Technology

Xu Qingrui Fan Baoqun
School of Management, Zhejiang University (Yu Quan), Hangzhou, P.R.China
School of Management, Zhejiang University ,YuGu Road 20, Hangzhou, 310027
Telephone: 0086(571)7951886, 7993120 Fax:0086(571)7951358
E-mail: sba_xuqr@ema.zju.edu.cn, or xqr@sba.zju.edu.cn

Abstract *Studies on Harmonious development of Science & Technology, Education and Economy(STEE) are hotspots in the world under Knowledge Economy and Globalization era whose base is High Technology. However there are very few researches on harmonious development of Chinese Science & Technology, Education and Economy(CSTEE). Thus, this paper tries to study CSTEE system with System Dynamics Method, model it and test some combined patterns and policies. After Modeling and analyzing the CSTEE system, this paper also gives suggestions on Science & Technology, and Education input strategies in China based on better harmonious development of CSTEE.*

Keywords *Harmonious Development of Chinese Science and Technology, Education and Economy; System Dynamics Modeling; Science & Technology and Education input Strategies;*

1 Introduction

System Dynamics Method(SDM) is a kind of effective way to describe internal structure, interaction and evolutionary behaviors of complex systems(Forrester,1980). Compared with other analysis tools, System Dynamics Method have two obvious advantages in analyzing non-liner complex systems and making decisions. First is that SDM is helpful to solve problems from systemic exterior(exogenous variable) to interior(endogenetic variable). The other is that SDM makes it easy and feasible to evaluate feasible scheme because SDM can show all possible results with system emulation and overcome traditional methods' non-intuitionisty. Many scholars study complex systems with SDM, such as Roberts(1979) and Senge(1990) and so on.

However there are very few researches on the complex systems--harmonious development of CSTEE with SDM. Therefore this paper tries to build system dynamics model of harmonious development of CSTEE with SDM in order to analyze and review issues of Chinese S&T and education input strategies. This paper will analyze mainly following four questions:

i) Dynamic change of Chinese R&D input and R&D input/GDP;
ii) Change on internal structure of R&D input
iii) Dynamic change of Chinese education input(EI) and EI/GDP
iv) Internal structural change of education input.

2 Model structure, causal relationship and flow map of CSTEE under high-technology

In system thinking, harmonious development of CSTEE must consider internal structures and interactive relationship among S&T, education and economy systems and have to consider the match relationship among them(see figure 1). According to figure 1, there are there subsystems: S&T subsystem, education subsystem and economy subsystem.. A brief causal effect loops about three subsystems is show as figure 2. Based on figure 1 and figure 2, we build a system dynamics model including three subsystems and more than 700 variables. As the space is limited, we omit material about stocks and flows.

Fig. 1 Model structure for harmonious development of CSTEE

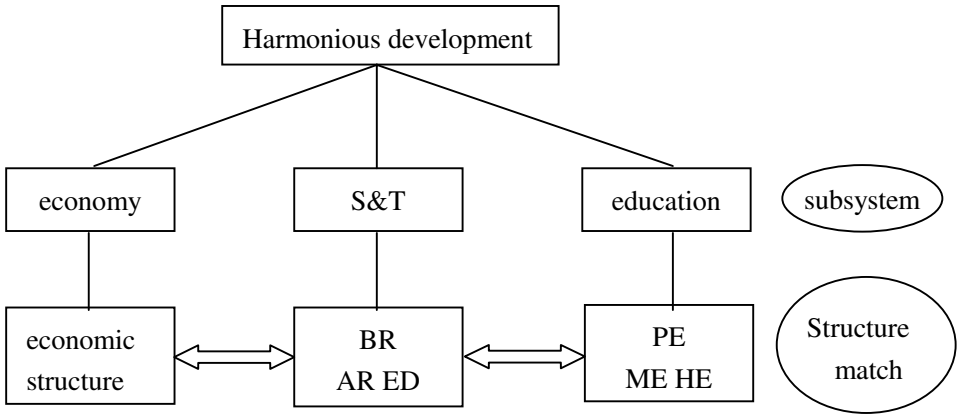
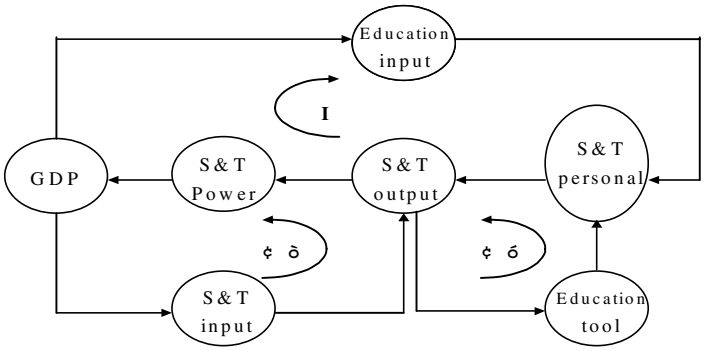


Fig.2 Brief causal relationship of STEE



3 Testing System Dynamics Model of CSTEE

To system dynamics model, rationality and validity are basic precondition for model effective emulation. Next this paper discusses the rationality and validity of CSTEE model with two key indicators: R&D expenditure and education input in China.

i) by comparing model emulation result with actual value of R&D expenditure, we can find the model is very good in being close to actual situation. (see table 1 and figure

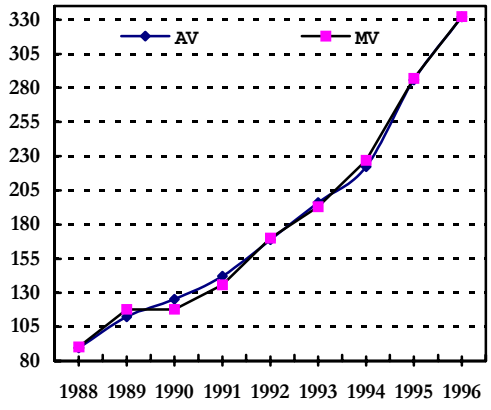
3).

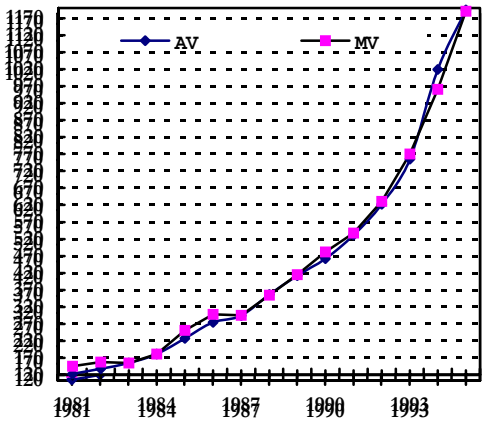
Table 1 Comparison on CSTEE model emulation and actual value of Chinese R&D expenditure unit: 100million yuan

Year	1988	1989	1990	1991	1992	1993	1994	1995	1996
AV	89.5	112.3	125.4	142.3	169	196	222.2	286	332
MV	90.4	114.92	122.5	143.1	166.0	197.9	224.75	281.5	332.2
E %	1	2.34	2.3	0.56	1.72	0.98	1.24	1.56	0.05

Note: AV: actual value; MV: model value; E: error

Figure 3 R&D expenditure comparison figure 4 education input comparison





ii) same situation is found in education input. (see table 2 and figure 4).

Table 2 Comparison on CSTEE model emulation and actual value of Chinese education expenditure unit: 100million yuan

Year	1987	1988	1989	1990	1991	1992	1993	1994	1995
AV	294	357	412	462	532	622	755	1019	1194
MV	295.5	354.9	415	468.5	537	631	757	986.3	1189
E	0.5	0.6	0.7	1.4	0.9	1.45	0.27	3.2	0.4

Note:See table 1

Therefore, the system dynamics modeling on harmonious development of CSTEE is effective and feasible.

4 Policy test and analysis

The growth patterns for R&D input and education input may be analyzed with four types:

Pattern 1) investment growth with steady ratio to GDP;
Pattern 2) investment growth with regular rate
Pattern 3) exponent growth
Pattern 4) logarithmic growth

Based on above four pattern, we can get 16 kinds of combined growth patterns with matching different education input pattern with different R&D expenditure pattern (see table 3). In order to evaluate different schemes, we choose three indicators: GDP (unit: 100 billion yuan), S&T personal (unit: 10 thousands) and Total factor productivity(TFP, unit: %). Respectively Emulating the 16 combined pattern, the results are shown as figure 5 to figure 12, and table 4 to table 11.

Table 3　16 kinds combined patterns of R&D input and education input

R&D input pattern education input pattern	Pattern 1	Pattern 2	Pattern 3	Pattern 4
Pattern 1	P_{11}	P_{12}	P_{13}	P_{14}
Pattern 2	P_{21}	P_{22}	P_{23}	P_{24}
Pattern 3	P_{31}	P_{32}	P_{33}	P_{34}
Pattern 4	P_{41}	P_{42}	P_{43}	P_{44}

For pattern 1 of education input(belongs to typical conservative and negative input strategy), the ratio of education input to GDP keeps same value each year, i.e. education expenditure/GDP=2.5%, then let R&D input patterns change from pattern 1 to pattern 4. The results of emulation are shown as figure 5 and table 4.

Fig. 5　combined patterns' results under pattern 1 of education input

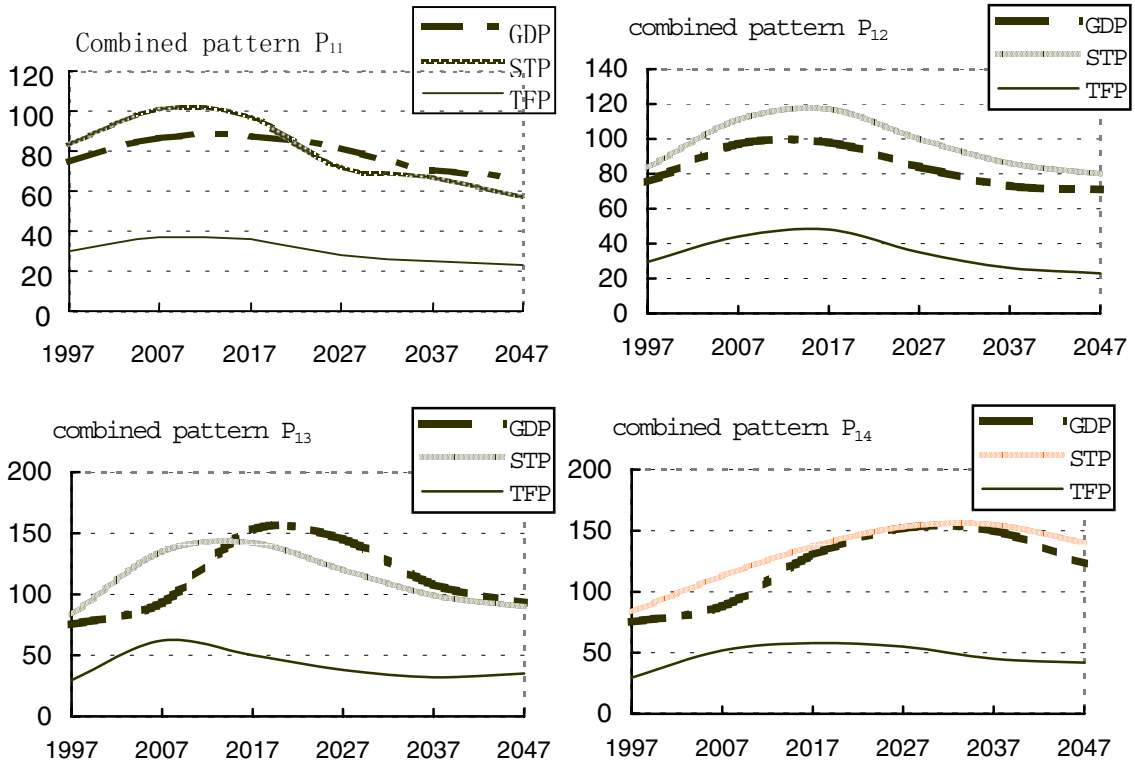


Table 4　Model emulation results of combined patterns P_{11}-P_{14}

		1997	2007	2017	2027	2037	2047
P_{11}	GDP	75.3	87.5	88	82.5	71.2	68
	STP	83.4	101	97.5	72	67	57
	TFP	29.6	37	36	28	25	23
P_{12}	GDP	75.3	97	98	84	73	71
	STP	83.44	111	117	100	86	80
	TFP	29.6	44	48	35	26	23
P_{13}	GDP	75.3	93	153	145	108	93
	STP	83.44	135	142	120	99	90
	TFP	29.6	62	50	38	32	35
P_{14}	GDP	75.3	88	130	152	150	123
	STP	83.44	113	137	153	155	140
	TFP	29.6	52	58	55	45	42

Pattern 2 to 4 of education input belongs to active input strategy. The results of model emulation are analyzed and shown as figure 5 to 7 and table 5 to 7.

Fig. 5 combined patterns' results under pattern 2 of education input

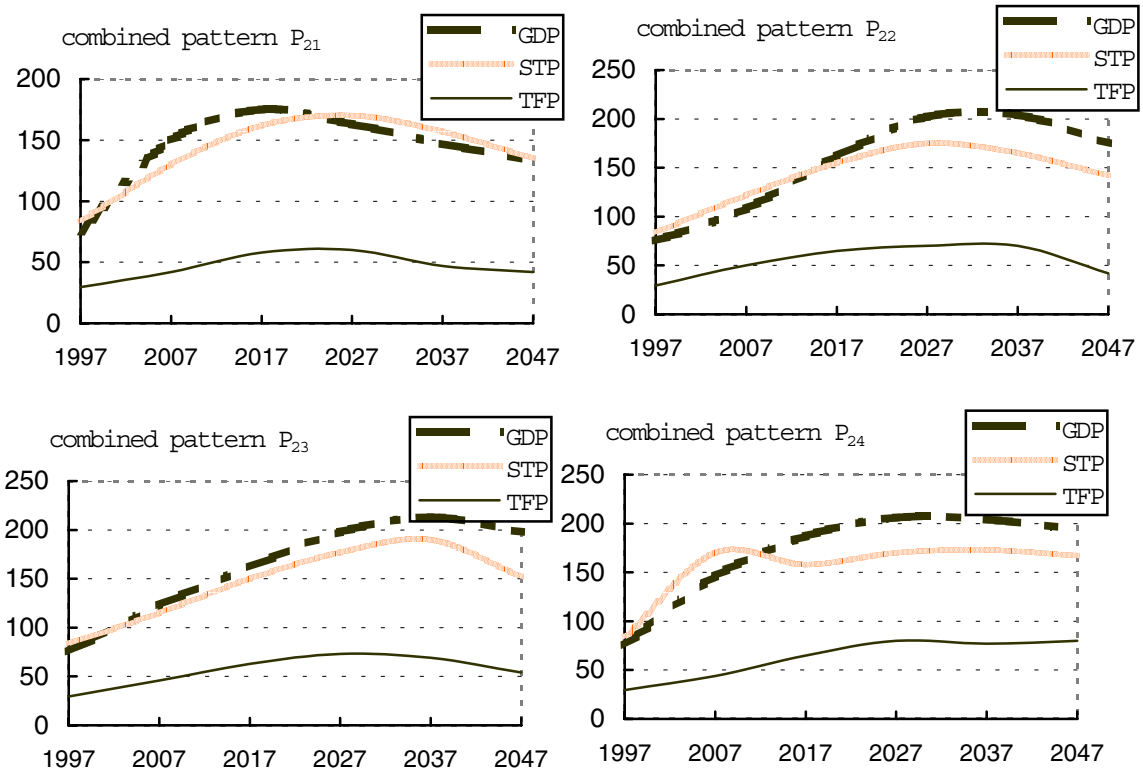
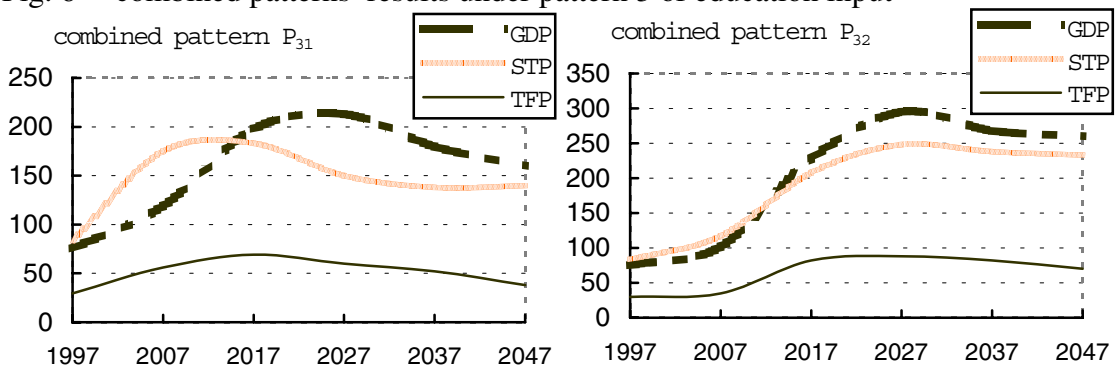


Table 5 Model emulation results of combined patterns from P_{21} to P_{24}

		1997	2007	2017	2027	2037	2047
P_{21}	GDP	75.3	150	175	163	147	133
	STP	83.44	130	162	170	157	135
	TFP	29.6	42	58	60	47	42
P_{22}	GDP	75.3	108	162	202	204	175
	STP	83.44	122	155	175	165	142
	TFP	29.6	50	65	70	70	42
P_{23}	GDP	75.3	123	162	198	213	198
	STP	83.44	115	150	177	190	152
	TFP	29.6	46	63	73	69	54
P_{24}	GDP	75.3	146	187	206	204	194
	STP	83.44	170	158	170	173	167
	TFP	29.6	44	65	80	77	80

Fig. 6 combined patterns' results under pattern 3 of education input



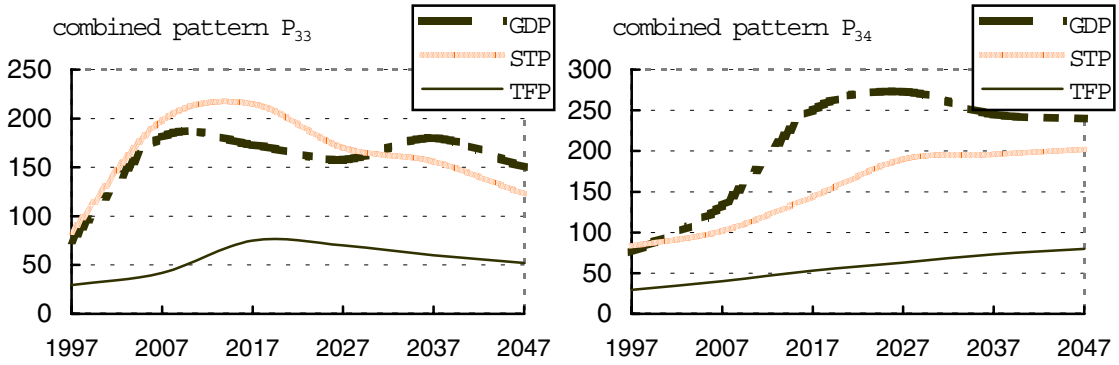


Table 6 Model emulation results of combined patterns from P_{31} to P_{34}

		1997	2007	2017	2027	2037	2047
P_{31}	GDP	75.3	119	198	213	180	160
	STP	83.44	175	183	150	138	140
	TFP	29.6	56	69	60	52	38
P_{32}	GDP	75.3	102	228	295	268	260
	STP	83.44	117	208	248	238	233
	TFP	29.6	35	82	88	82	70
P_{33}	GDP	75.3	181	173	158	180	150
	STP	83.44	198	215	170	156	123
	TFP	29.6	42	75	70	60	52
P_{34}	GDP	75.3	133	250	273	245	240
	STP	83.44	102	144	190	196	202
	TFP	29.6	40	53	63	73	80

Fig. 7 combined patterns' results under pattern 4 of education input

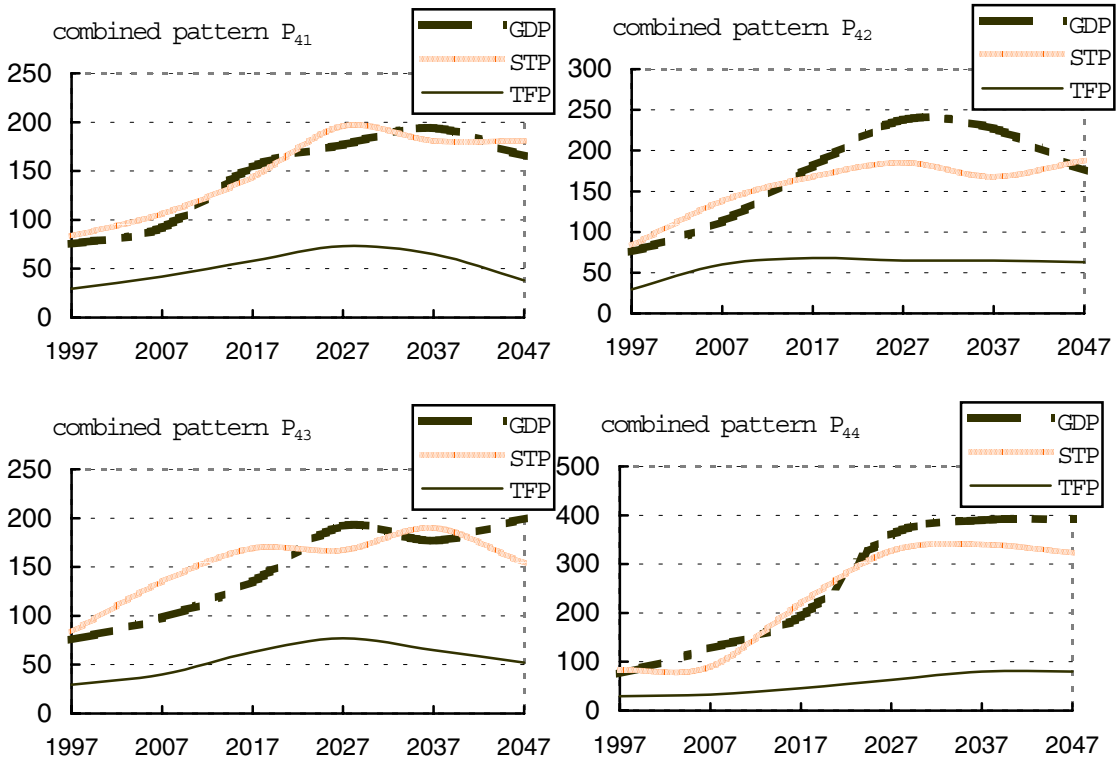


Table 7 Model emulation results of combined patterns from P_{41} to P_{44}

		1997	2007	2017	2027	2037	2047
P_{41}	GDP	75.3	92	154	177	194	165
	STP	83.44	106	144	196	181	181
	TFP	29.6	42	58	73	65	38
P_{42}	GDP	75.3	113	181	238	227	175
	STP	83.44	138	168	185	168	188
	TFP	29.6	60	68	65	65	63
P_{43}	GDP	75.3	98	135	192	177	200
	STP	83.44	135	169	167	190	154
	TFP	29.6	40	63	77	65	52
P_{44}	GDP	75.3	127	193	360	390	392
	STP	83.44	90	220	327	340	323
	TFP	29.6	33	46	63	80	80

Table 8 collection of different patterns results and evaluation of feasibility

		1997	2007	2017	2027	2037	2047	Feasibility
P_{11}	GDP	75.3	87.5	88	82.5	68	71.2	−
	STP	83.4	101	97.5	72	57	67	
	TFP	29.6	37	36	28	23	25	
P_{12}	GDP	75.3	97	98	84	71	73	−
	STP	83.4	111	117	100	80	86	
	TFP	29.6	44	48	35	23	26	
P_{13}	GDP	75.3	93	153	145	93	108	−
	STP	83.4	135	142	120	90	99	
	TFP	29.6	62	50	38	35	32	
P_{14}	GDP	75.3	88	130	152	123	150	+
	STP	83.4	113	137	153	140	155	
	TFP	29.6	52	58	55	42	45	
P_{21}	GDP	75.3	150	175	163	133	147	−
	STP	83.4	130	162	170	135	157	
	TFP	29.6	42	58	60	42	47	
P_{22}	GDP	75.3	108	162	202	175	204	+
	STP	83.4	122	155	175	142	165	
	TFP	29.6	50	65	70	42	70	
P_{23}	GDP	75.3	123	162	198	198	213	−
	STP	83.4	115	150	177	152	190	
	TFP	29.6	46	63	73	54	69	
P_{24}	GDP	75.3	146	187	206	194	204	++
	STP	83.4	170	158	170	167	173	
	TFP	29.6	44	65	80	80	77	
P_{31}	GDP	75.3	119	198	213	160	180	−
	STP	83.4	175	183	150	140	138	
	TFP	29.6	56	69	60	38	52	
P_{32}	GDP	75.3	102	228	295	260	268	+++
	STP	83.4	117	208	248	233	238	
	TFP	29.6	35	82	88	70	82	

Table 8 continued

P_{33}	GDP	75.3	181	173	158	150	180	—
	STP	83.4	198	215	170	123	156	
	TFP	29.6	42	75	70	52	60	
P_{34}	GDP	75.3	133	250	273	240	245	++++
	STP	83.4	102	144	190	202	196	
	TFP	29.6	40	53	63	80	73	
P_{41}	GDP	75.3	92	154	177	165	194	+
	STP	83.4	106	144	196	181	181	
	TFP	29.6	42	58	73	38	65	
P_{42}	GDP	75.3	113	181	238	175	227	—
	STP	83.4	138	168	185	188	168	
	TFP	29.6	60	68	65	63	65	
P_{43}	GDP	75.3	98	135	192	200	177	—
	STP	83.4	135	169	167	154	190	
	TFP	29.6	40	63	77	52	65	
P_{44}	GDP	75.3	127	193	360	392	390	+++++
	STP	83.4	90	220	327	323	340	
	TFP	29.6	33	46	63	80	80	

Note:— stands for low feasibility; + stands for high feasibility.

According to table 8, it is obvious that feasibility of combined patterns P_{24}, P_{32}, P_{34} and P_{44} is high. Above patterns mean different input combination. (see table 9)

Table 9 special meanings of four feasible patterns

Combined pattern	Input mode
P_{24}	Investment growth as regular rate of education input and logarithmic growth of R&D input
P_{32}	Exponent growth of education input and growth as regular rate of R&D input
P_{34}	Exponent growth of education input and logarithmic growth of R&D input
P_{44}	Logarithmic growth of education input and logarithmic growth of R&D input

Based on above four feasible combined patterns, this paper also emulates and analyzes the tendency of internal structural change of different patterns. The emulation results are shown as table 10 to table 13.

Speaking to combined pattern P_{24}, the possible trends of internal structural change of education input are that the ratio of primary education input may decline from 53 percent of education input in 1996 to 50 percent of 2050, middle education input keep at 29~30 percent of total education expenditure, and higher education input increase from 17 percent of 1996 to the max value 20% about 2020, then last to 2050 or so. The allocation strategies of R&D input may be that the ration of Basic Research increases from 5% to max value 9% of 2020, then declines slightly and last 7.5 % to 2050; Applied Research expenditure may decline from 30 percent of 1996 to 25 percent of 2050; and Experiment Development may increase from 64 percent of 1996 to 68 percent of 2050 or so.

Table 10 Emulation results of internal structural change of combined pattern P_{24}

Year	1997	2002	2007	2012	2017	2022	2027	2032	2037	2047
EI/GDP	2.5	3.75	5	6.25	7.5	8.75	10	11.25	12.5	13.75
R&D/GDP	0.496	1.119	1.663	1.971	2.073	1.974	1.794	1.697	1.649	1.610
PE	53	50.24	49.63	49.25	49.45	49.83	50.00	50.08	50.07	50.18
ME	30	30.58	30.51	30.60	30.47	30.30	30.10	29.86	29.80	29.73
HE	17	19.17	19.85	20.13	20.07	19.85	19.88	20.05	20.11	20.07
BR	5.999	6.918	8.137	8.983	9.110	8.927	8.703	8.350	7.945	7.580
AR	30.20	29.37	28.40	27.52	26.47	25.45	24.82	24.37	24.35	24.51
ED	63.79	63.70	63.45	63.48	64.41	65.61	66.46	67.27	67.69	67.90

Note: EI: education input; R&D: R&D expenditure; PE: ratio of primary education expenditure; ME: ratio of middle education expenditure; HE: ratio of higher education expenditure; BR: basic research; AR: applied research; ED: experiment development.

To education and R&D structural change of combined pattern P_{32} and P_{34}, detailed strategies are shown in table 11 and table 12.

Table 11 Emulation results of internal structural change of combined pattern P_{32}

Year	1997	2002	2007	2012	2017	2022	2027	2032	2037	2047
EI/GDP	2.5	2.36	2.227	2.164	2.133	2.390	2.948	3.883	5.125	6.033
R&D/GDP	0.496	0.74	0.992	1.24	1.488	1.736	1.984	2.231	2.48	2.728
PE	53	47.7	47.33	46.44	44.44	43.86	44.14	42.84	45.46	47.23
ME	30	33.1	32.25	29.76	29.13	27.77	27.43	27.82	25.12	24.27
HE	17	19.11	20.40	23.78	26.41	28.35	28.42	29.33	29.40	28.49
BR	5.999	6.91	8.193	9.551	10.82	12.32	14.46	17.39	17.62	17.44
AR	30.20	29.3	28.58	28.60	29.06	29.85	30.85	31.70	35.61	33.69
ED	63.79	63.7	63.21	61.84	60.10	57.81	54.68	50.90	46.75	42.86

Note : see table 10.

Table 12 Emulation results of internal structural change of combined pattern P_{34}

Year	1997	2002	2007	2012	2017	2022	2027	2032	2037	2047
EI/GDP	2.5	2.360	2.227	2.164	2.133	2.390	2.948	3.883	5.125	6.033
R&D/GDP	0.496	1.119	1.663	1.971	2.073	1.974	1.794	1.697	1.649	1.610
PE	53	51.49	50.59	46.41	42.44	42.69	41.11	39.48	40.15	42.72
ME	30	29.38	28.57	29.79	31.13	28.95	27.43	26.81	25.06	23.80
HE	17	19.11	20.83	23.78	26.41	28.35	31.45	33.70	34.77	33.47
BR	5.999	6.898	8.116	9.515	10.98	12.86	15.41	18.41	22.19	26.57
AR	30.20	29.57	29.27	29.56	30.20	31.61	33.49	35.33	36.82	37.92
ED	63.79	63.53	62.61	60.91	58.81	55.51	51.08	46.25	40.97	35.50

Note : see table 10.

To combined pattern P_{44}, the possible trends of internal structural change of education input are:(see table 13)

a) the ratio of primary education input may decline from 53 percent of education input in 1996 to min value 40 percent of year 2010, then return to 46 percent of year 2050 or so;
b) middle education input would keep at 29~30 percent of total education expenditure;
c) higher education input increases from 17 percent of 1996 to the max value 29% about 2020, then declines slightly to 26 % of year 2050 or so.

The allocation strategies of R&D input may be:

a) the ration of Basic Research increases from 5% to max value 19% of 2030, then declines slightly and last 17 % to year 2050 or so;
b) Applied Research expenditure may keep as 29~30 percent of total R&D expenditure;
c) Experiment Development may decline from 64 percent of 1996 to 53 percent of year 2050 or so.

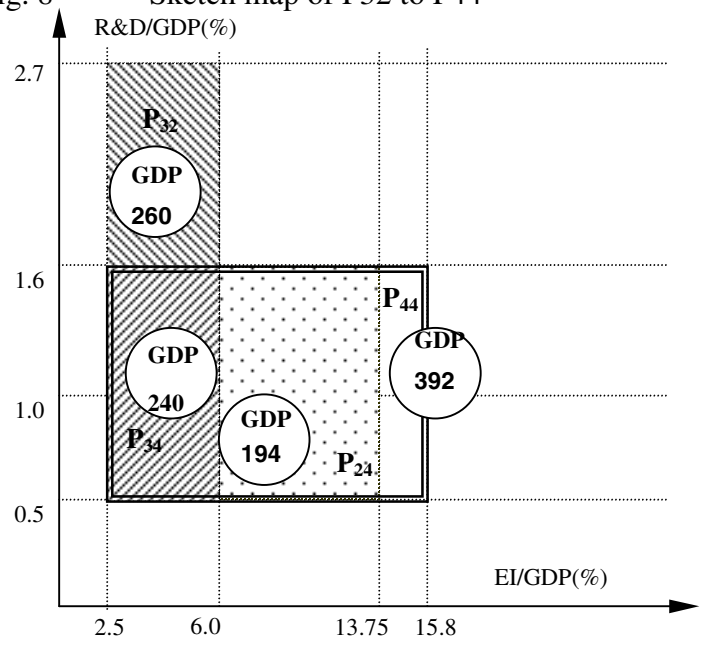
Table 13 Emulation results of internal structural change of combined pattern P_{44}

Year	1997	2002	2007	2012	2017	2022	2027	2032	2037	2047
EI/GDP	2.5	5.35	15.8	15.55	15.37	15.24	14.69	14.46	14.48	14.57
R&D/GDP	0.496	1.119	1.66	1.971	2.073	1.974	1.794	1.697	1.649	1.610
PE	53	43.7	40.1	39.33	42.13	45.33	47.17	48.21	48.59	46.2
ME	30.0	30	31.9	31.62	29.41	27.04	25.99	25.38	25.65	30
HE	17	23.8	26.2	27.90	29.04	28.45	27.61	26.83	26.40	25.74
BR	5.999	6.75	7.57	8.855	10.61	13.76	17.03	18.89	19.14	18.31
AR	30.20	30.6	31.2	30.72	29.57	28.04	26.92	26.72	27.88	29.82
ED	63.79	62.5	61.2	60.42	59.80	58.19	56.04	54.37	52.97	51.85

Note : see table 10.

Compared with GDP and the result shown as table 10 to table 13, this paper gives an sketch map of four different feasible patterns. (see fig. 8) Different areas of Fig 8 represent the respective scope of four feasible patterns.

Fig. 8 Sketch map of P32 to P44

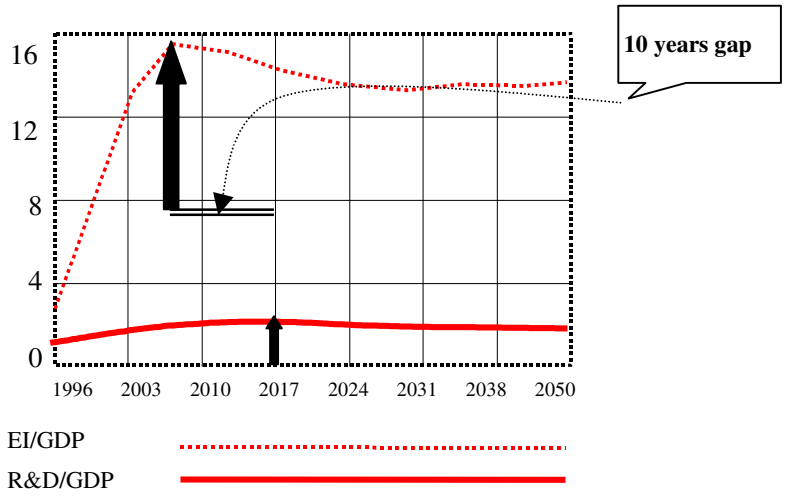


In order to ensure Chinese economic growth fastest and total factor productivity growth biggest before half of next century, the combined pattern P_{44} is the best choice, i.e. logarithmic growth of education and R&D input. This pattern is also very fit to the situation of China. Because the scale of R&D and education input in China was too low in last several decades and did not keep up with the pace of economic development. Therefore, Chinese R&D and education input should grow with a fast rate. In short-term, the emphasis of Chinese R&D input should be the firms which pursue the work of Applied Research and Experiment Development so that firms can become the main body of technology innovation. In long-term, China have to enhance the area of Basic Research by investing vigorously R&D funds in Basic Research and building the Universities and Colleges as base of Basic Research and high technology under knowledge era of 21st Century.

For allocation of education input, in short-term, the emphasis of education investment should be primary and middle education. And in long-term, China must develop actively higher education in order to provide the base of person with ability for scientific and technological development and intensive knowledge competition of 21st Century. Moreover from the result of pattern P44, we can find that the growth of

Chinese education input is earlier than growth of R&D input about ten years.(see fig. 9) According to pattern P44, the ratio of education input will reach max value 15 % in year 2005~2007, but the max value of R&D input in year 2015~2017.

Fig. 9 The Sketch map of education input growth ahead of R&D input



5 concluding remarks

The conclusions by our research are:

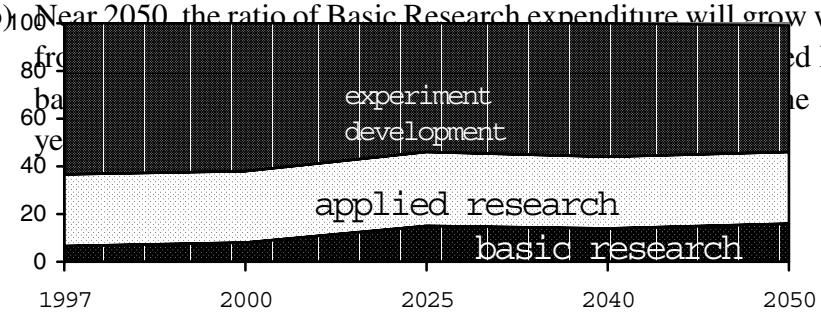
(1) In order to ensure Chinese economic growth fastest and total factor productivity growth biggest before half of next century, the combined pattern P_{44} is the best choice, i.e. logarithmic growth of education and R&D input. The year 2007 will be dividing line for logarithmic growth of education input. The mode of education expenditure growth should adopt high-level logarithmic growth before year 2007 and the ratio of education input will reach the max value 15 % in 2007. The mode of education expenditure growth should adopt low-level logarithmic growth after year 2007 and basically keep same level during 2020 to 2050. Year 2017 will be the dividing line of R&D input. The mode of R&D expenditure should adopt high-level logarithmic growth before year 2017 and reach the max value 1.6 percent of total R&D expenditure.

(2) The growth rate of education input will be faster than that of R&D input during year 2000 to year 2010.

(3) In order to ensure economic development with faster rate, better performance and better relationship among S&T, education and economy in the future 50 years, it is necessary for structure of R&D and education to adjust as following:

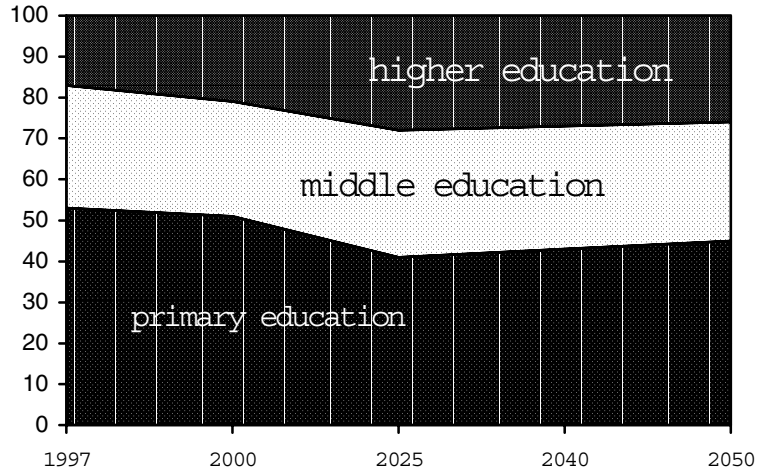
a) During year 2000 to 2025, the ratio of Basic Research should increase from 6.6% of year 1997 to 15 percent of year 2025, Applied Research keep in 30 % or so and Experiment Development decline from 63.4% of year 1997 to 55% of year 2025.

b) Near 2050, the ratio of Basic Research expenditure will grow with big scope, fr ed Research keep ba e to 53~55% of ye



c) During year 2000 to 2020, the ratio of higher education expenditure should increase from 17% of year 1997 to 28% of year 2020, middle education increase to 31 % of year 2020 and primary education decline from 53% of year 1997 to 41% of year 2020.

d) Near 2050, the ratio of higher education expenditure will reach 26% of total education input or so, middle education keep at the level of 28~30%, and the primary education decline to 46% or so of year 2050.



e) The time education input grows to max value may be earlier 10 years than the time of R&D input.

Main References

Qingrui XU, Junjie Li et al(1988). *Science-Technology, Education and Economy System Dynamic Model*, Proceedings of ICSSE'88, International Academic Publishers, Beijing.

Qingrui XU(1986). *R&D management*. High Education Publishers, Beijing.

Qingrui XU, Jin Chen (1991). *Resource Allocation on the Technological Innovation*, Proceedings of International Conference of System Dynamics Society, Bangkok.

Qingrui XU(1990). *Managing Technological Innovation*, Zhejiang University Press, Hangzhou.

Roberts,E.B.(1979).*Managerial Applications of System Dynamics*, The MIT Press,Cambridge.

Senge,P.(1990).*The fifth Discipline: The Art and Practice of the Learning Organization*, Century Business: London.